CYLINDER BY CYLINDER ENGINE MODELING OF SINGLE CYLINDER 4 STROKE ENGINE FOR CONTROL SYSTEM DEVELOPMENT

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Report submitted in partial fulfillment of the requirements for the award of Bachelor of Mechanical with Automotive Engineering

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JUNE 2012

ABSTRACT

The objective of this thesis is to design and simulate cylinder by cylinder engine model for control oriented study based on single cylinder four stroke engines, which combines both physical formulae, such as engine geometries, and empirical formulae. The engine performance, torque and power is calculated by integrating the pressure inside cylinder within one engine cycle. The importance of this study is to predict the engine performance parameters such as indicated work, brake power, and torque that provided with air fuel ratio data and detail geometrical specifications. The model of FZ150i full engine specifications is used for simulation in order to predict the engine performance. The model is simulated between 2000 to 6000 rpm of engine speed range. From this simulation, the result shows that it is almost same with the experimental data by Sitthiracha (2006). Without build the real engine, all the engine performance parameter can be calculated from this simulation, and reduced the time and cost.

ABSTRAK

Objektif tesis ini adalah untuk mereka bentuk dan simulasi silinder dengan menggunakan model enjin silinder bagi kajian kawalan yang berdasarkan enjin empat strok dimana ia mengabungkan kedua-dua formula fizikal, seperti geometrik enjin dan formula empirik. Prestasi enjin, tork dan kuasa boleh dihitung dengan mengintegrasikan tekanan dalam silinder bagi tempoh satu kitaran enjin. Kepentingan kajian ini ialah untuk meramal prestasi parameter enjin seperti kerja tertunjuk, kuasa brek dan tork dengan menggunakan data nisbah bahan api udara dan spesifikasi geometrik yang lebih terperinci. Spesifikasi enjin penuh Model FZ150i digunakan dalam simulasi supaya dapat meramal prestasi enjin. Model disimulasikan dengan kelajuan enjin pada kelajuan 2000 hingga 6000 rpm. Hasil keputusan simulasi ini menunjukkan ianya hampir sama dengan data eksperimen oleh Sitthiracha (2006). Tanpa membina enjin yang sebenar, kesemua prestasi parameter enjin boleh dihitung daripada program simulasi ini dimana ianya dapat menjimatkan masa dan kos.

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LIST OF SYMBOL

a	Crank Radius
A	Exposed Combustion Chamber Surface Area
AR	Reference Area
b	Cylinder Bore
CD	Discharge Coefficient
Cf	Frictional Loss Factor
Cheat	Charge Heating Factor
Cm	Mean Piston Speed
Div	Inlet Valve Diameter
Dv	Valve Diameter
f	Fraction of Heat Added
h	Convection Heat Transfer Coefficient
HV	Heating Value of Fuel
IVC	Inlet Valve Close Angle After BDC
IVO	Inlet Valve Open angle Before TDC
k	Specific Heat Ratio
l	Connecting Rod Length
Liv,max	Maximum Inlet Valve Lift
Lv	Valve Lift Function
mair,stoich	Theoretical Amount of Air Requirement
m	Mass Flow Rate
ma	Air Mass
N	Engine Speed
P	Pressure Inside Cylinder

Pe	Effective Power
Qin	Overall Heat Input
Q	Heat Addition
$Qloss$	Heat Transfer
R	Gas Constant
s	Stroke
Tg	Temperature of Cylinder Gas
$Texh$	Exhaust Gas Temperature
Tw	Cylinder Wall Temperature
pf	Friction Mean Effective Pressure
pme	Brake Mean Effective Pressure
$T0$	Stagnation Temperature
V	Cylinder Volume
Vd	Displacement Volume
$\Delta\theta$	Duration of Heat Addition
ε	Compression Ratio
ηv	Thermal Efficiency
θ	Crank Angle
$\theta 0$	Angle of Start of Heat Addition
ρa	Air Density

LIST OF ABBREVIATION

SYMBOL	SPECIFICATION
BDC	Bottom Dead Center
MVEM	Mean Value Engine Model
CCEM	Cylinder-by-cylinder Engine Model
EGR	Exhaust Gas Recirculation
TDC	Top Dead Center
WOT	Wide Open Throttle
HC	Hydrocarbon
rpm	Round per Minute
CO	Carbon Monoxide

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CHAPTER 1

INTRODUCTION

1.0 PROJECT TITLE

Cylinder by Cylinder Engine Modeling of Single Cylinder 4 Stroke Engine For Control System Development.

1.1 PROJECT BACKGROUND

The cylinder by cylinder engine model (CCEM) is a mathematical model derived from basic physical principles such as conservation of mass and energy equations. CCEM can predict an engine's main external variables such as crankshaft speed and manifold pressure, and important internal variables, such as volumetric and thermal efficiencies.

The model consists of three main components: the throttle model, exhaust model, and crank-slider model. Adjusting the parameters allow the model to be used for new engines of interest. The importance of this study is to predict the engine performance parameters such as indicated work, brake power, and torque that provided with air fuel ratio data and detail geometrical specifications.

The method that has been chosen for this project is using simulation to predict the engine performance parameters. This is because this method can save time and reduce the spending of money to build engine test-rig for experimental work.

1.2 PROBLEM STATEMENT

In order to develop a new electronic control system for an engine, a control oriented model need to be proposed to assist the initial design and development work. The control oriented model shall be based on cylinder-to-cylinder approach which include the throttle body, exhaust and crank-slider model.

1.3 PROJECT OBJECTIVES

The objective of this study is to design and simulate cylinder by cylinder engine model for control oriented study based on single cylinder four stroke engines.

1.4 PROJECT SCOPE

Basically, this analysis based on:

1. The model is based on single cylinder four strokes SI Engine.
2. The model consisted of dynamics model of air-flow, fuel-flow and crankshaft dynamics.
3. The model is limited to physical/geometrical representation of the engine only. The fuel injection with it associated controller is not part of current scope.
4. The model used to predict engine performance parameters such as indicated power, brake power, torque and provided with air fuel ratio data and detail geometrical specifications.
5. The model used to simulate engine operating range from idle speed condition until achievable maximum speed and load.

1.5 FLOW CHART OF STUDY

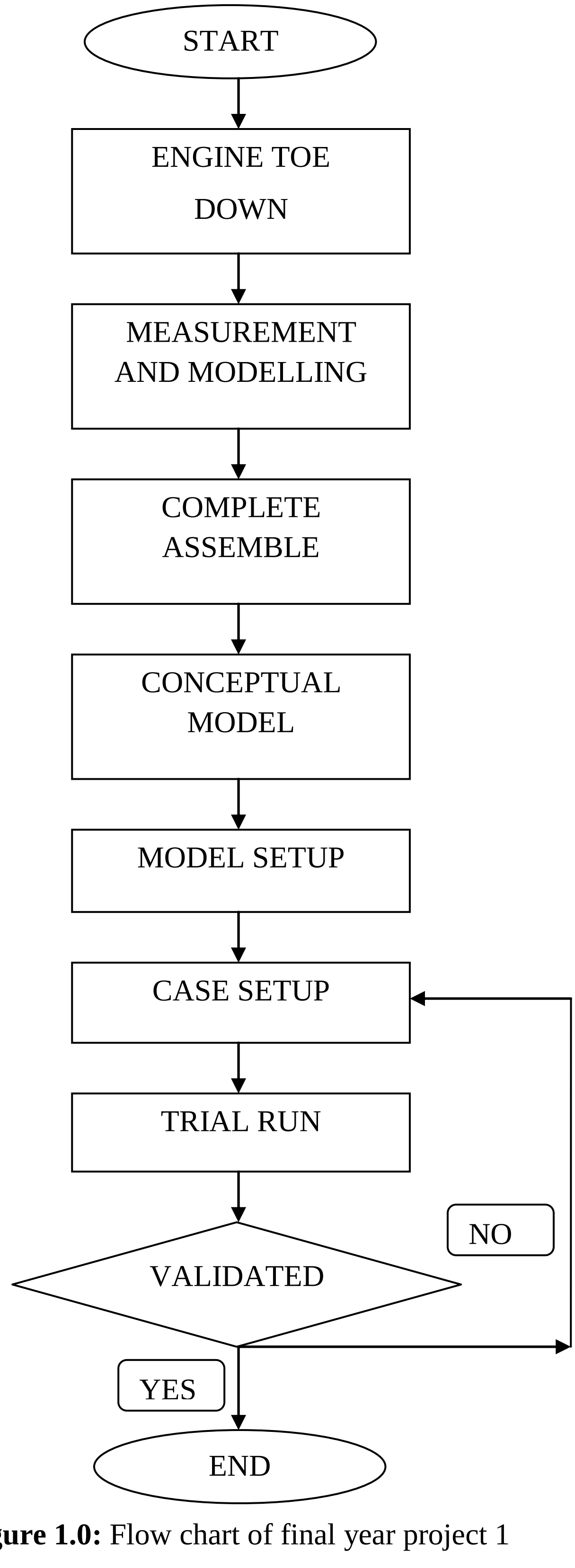


Figure 1.0: Flow chart of final year project 1

1.6 SUMMARY

The CCEM is a mathematical model derived from basic physical principles such as conservation of mass and energy equations. The importance of this study is to predict the engine performance parameters such as indicated work, brake power, and torque. The model is provided with air fuel ratio data and detail geometrical specifications to perform the simulation.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter, introductions about cylinder by cylinder engine modeling for control system development of a single cylinder-four-stroke engine is discussed. It is used mainly for design and simulating the system of engine without spending much time on experimental bench. From that the engine parameters from the output such as torque, brake power, and indicated work can be determined. A CCEM is describing each cylinder individually, could prove a useful and also needed to model cylinder individual phenomena such as misfire when developing systems for diagnostics. This simulation method allows the engine designed to test different parameters without building real parts or even real engines.

2.1 INTERNAL COMBUSTION ENGINE PRINCIPLE OPERATION

2.1.1 Spark Ignition Engine

The spark ignition engine is used in variety application such as cars, motorcycle, small engine generator and etc.

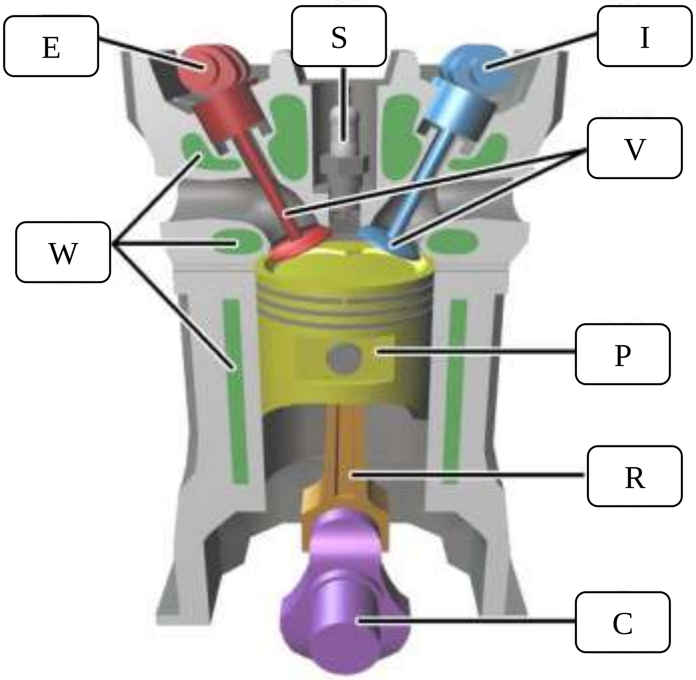


Figure 2.1: Schematic of spark ignition engine

Source: Stephen (2006)

Where:

E	-	Exhaust camshaft
I	-	Intake camshaft
S	-	Spark plug
V	-	Valves
P	-	Piston
R	-	Connecting rod
C	-	Crankshaft
W	-	Water jackets

2.1.2 Basics of Four Stroke Engine System

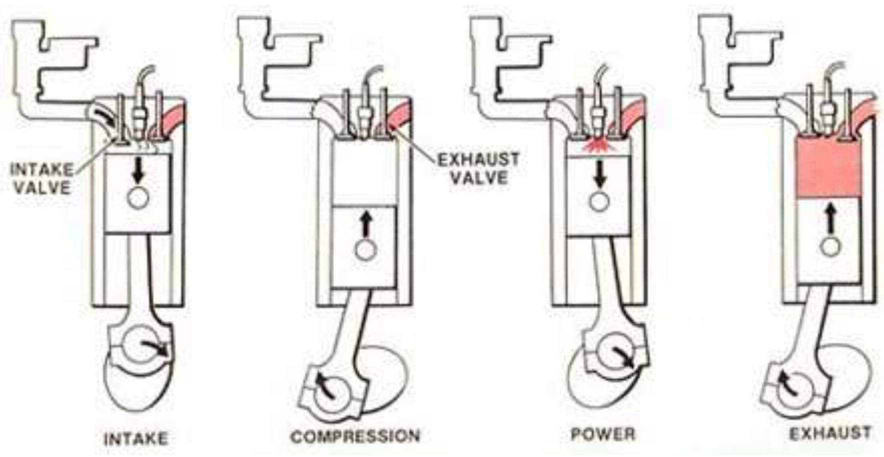


Figure 2.2: Four-Stroke Engine System

Source: Sitthiracha (2006)

I. **Intake Stroke** – The inlet valve is opened and the fuel/air mixture is drawn in as the piston travels down.

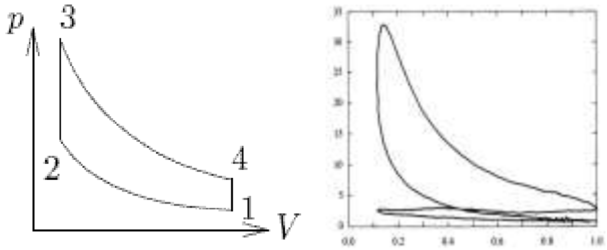
II. **Compression Stroke** – The inlet valve is closed and the piston travels back up the cylinder compressing the fuel/air mixture. And before the piston reaches the top of its compression stroke a spark plug emits a spark to combust the fuel/air mixture and the number of degrees before the top its stroke is the ignition advance which is called at ‘top dead center' (TDC).

III. **Combustion Stroke** – The piston is now forced down by the pressure wave of the combustion at top dead center and it is called as the power stroke. The engine power is derived from this stroke.

IV. **Exhaust Stroke** – The exhaust valve is opened and the piston travels back up expelling the exhaust gases through the exhaust valve and at the top of this stroke the exhaust valve is closed. Then, this process was repeated.

The above is the cycle of operation of one cylinder of a 4-stroke engine which has two or more cylinders acting in concert with each other to produce the engine power. It is interesting to note that one complete engine cycle takes two revolutions but that individual valves and spark plugs only operate once in this time when their timing needs to be taken from a half engine speed signal, or we call it as the camshafts speed.

With models for each of these processes, the simulation of complete engine cycle can be built up and be analyzed to provide information on engine performances. These ideal models that describe characteristic of each process are proposed. However the calculation needs information from each state as shown in Fig.2.3a and Fig.2.3b.



(a) (b)

Figure 2.3: Pressure-volume diagram of Otto cycle:
(a) Ideal, (b) real

Source: Zeng et. al,(2004)

Overall engine work can be determined by integrating the area under the pressure-volume diagram and there are so many previous works concerned mainly prediction the pressure inside the combustion chamber (Zeng et. al, 2004). But the pressure and volume are influenced by engine geometries during variation of crank angle. Then the pressure and displacement volume are needed to convert as functions of crank angle. Then Kirkpatrick et. al (2005) proposed the method that can calculate the pressure and volume at any crank angle. And the combustion process can be described by the simple correlation, (Heywood, 1988).

The results from Zeng et. al (2004), indicated that heat transfer from inside the cylinder to engine cooling water had much influences on the pressure inside the cylinder and the heat transfer function is needed to take into account in the model.

Many researchers reported that the mass of mixture that flows into the cylinder during intake stroke is a very importance parameter (Andersson, 2002), by Heywood, (1988), because it affects amount of fuel which mixes with the air. By combining the ideal gas law and volumetric efficiency, this mass can be determined and it is very difficult to evaluate because they are affected by many factors, and for examples the manifold geometries and valve timing, (Heywood, 1988). So Kuo et. al (1996) assumed that the pressure inside manifold and inside the cylinder is the same value, and the effect of volumetric efficiency can be neglected. But Kuo (1996), used corrective equation from real experiment to compensate the errors. While Zeng and Assanis (2004), took the effect of volumetric efficiency into account.

However the data were obtained from the real experiment and stored in a 3-dimension table by relation between engine speed and intake manifold pressure. The combining of those methods that are mentioned above can predict the engine performances precisely if some testing data are known, mainly the volumetric efficiency.

2.2 CONTROL ORIENTED MODELING

There are numerous ways of describing reality through a model (Ramstedt and Silverlind, 2001). Some are more complex than others and the different approaches may differ in both structure and accuracy.

From previous study, a model of a four-cylinder spark ignition engine and capability to model an internal combustion engine from the throttle to the crankshaft output by Crossley and Cook (1991). It is used well-defined physical principles supplemented, where appropriate, with empirical relationships that describe the system's dynamic behavior without introducing unnecessary complexity, and it have some relation with this study.

2.2.1 Physical sub-model

This example describes the concepts and details surrounding the creation of engine models with emphasis on important control oriented modeling techniques. The basic model uses the enhanced capabilities of control oriented modeling to capture time-based events with high accuracy. During this simulation, a triggered subsystem models the transfer of the air-fuel mixture from the intake manifold to the cylinders via discrete valve events. The places takes the concurrently with the continuous-time processes of intake flow, torque generation and acceleration.

The second model adds an additional triggered subsystem that provides closed-loop engine speed control via a throttle actuator. This model can be used as standalone engine simulations and also can be used within a larger system model, such as an integrated vehicle and power train simulation in the development of a traction control system. This model is based on published results by Sitthiracha (2006). It describes the simulation of a four-cylinder spark ignition internal combustion engine. They work also shows how a simulation based on this model was validated against dynamometer test data. The following sections are analyzing the key elements of the engine model that were identified by them:

I. Throttle
II. Intake manifold
III. Mass flow rate
IV. Compression stroke
V. Torque generation and acceleration

I. Throttle

The first element of the model is the throttle body. The control input is the angle of the throttle plate. The rate at which the model introduces air into the intake manifold can be expressed as the product of two functions which is an empirical function of the throttle plate angle only and as the function of the atmospheric and manifold pressures. And in cases of lower manifold pressure (high pressure), the flow rate that is through the throttle body is sonic and is only as a function of the throttle angle. This model accounts for this low pressure behavior with a switching condition in the compressibility equations shown in Equation 1.

II. Intake Manifold

The simulation models the intake manifold as a differential equation for the manifold pressure. The difference in the incoming and outgoing mass flow rates represents the net rate of change of air mass with respect to time. This quantity, according to the ideal gas law, is proportional to the time derivative of the manifold pressure. Note that, unlike the model of Crossley and Cook (1991), although this can easily be added, this model doesn't incorporate exhaust gas recirculation (EGR).

III. Intake Mass Flow Rate

The mass flow rate is a function of the manifold pressure and the engine speed in order to determine the total air charge pumped into the cylinders, simulation integrates the mass flow rate from the intake manifold and samples it at the end of each intake stroke process. This is determines the total air mass that is present in each cylinder after the intake stroke and before compression.